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Graphene Nanocomposite Modified Glassy Carbon Electrode: As a Sensing Platform for Simultaneous Determination of Methyldopa and Uric Acid

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Fe_3O_4@SiO_2/GO nanocomposite was synthesized and used for surface modification of glassy carbon electrode. This modified electrode was used for electrochemical determination of methyldopa (MD) in the presence of uric acid (UA). Operational parameters such as amount of solution pH and scan rate which affected the analytical performance of the modified electrode were optimized. The calibration curve for MD was linear in the range of 0.1–400.0 μM with the detection limit (S/N=3) of 86.0 nM. The modified electrode was successfully applied for the determination of MD and UA in some real samples

Keywords: Methyldopa, Uric acid, Nanocomposite, Graphene, Glassy Carbon Electrode

1. INTRODUCTION

Methyldopa (MD), is in a category of medications called antihypertensive and widely prescribed for treating high blood pressure. It probably acts by relaxing the blood vessels whereby blood can circulate more freely through the vessels. The antihypertensive effect of MD results from its metabolism, alphamethyl norepinephrine, which lowers arterial pressure by stimulation of central inhibitory alpha-adrenergic receptors, false neurotransmission, and/or reduction of plasma renin

activity. It has been demonstrated that MD cause a net reduction in the tissue concentration of serotonin, dopamine, norepinephrine, and epinephrine [1]. Variation in the concentration of MD in the body may influence on its bioavailability and biopharmaceutical properties and subsequently, its magnitude of action. Therefore, for achieving a better curative effect and a lower toxicity, it is crucial to rapidly control the content of MD in biological fluids and pharmaceutical formulations [2]. According to above mentioned points, determination of this drug is important and it has been considered by researchers using several analytical methods [3-6].

Uric acid (UA) presents in body and is considered as an extremely important biological substances which is a main end product of purine catabolism. In the body an enzyme called xanthine oxidase is responsible for catalyzing the formation of UA from xanthine and hypoxanthine which themselves are produced form other purines. In healthy ones, most of the produced UA is filtered out by kidneys and went out from the body mainly in urine and somewhat in stool insofar as UA concentration maintains in the range of 0.24 to 0.52 mM in blood [7]. Elevated UA levels over this range can generate many diseases for example gout, high blood pressure, kidney disease, leukemia, pneumonia, cardiovascular diseases, high cholesterol and multiple sclerosis [8]. Therefore, it is very important to determine UA concentration in biological fluids as an early stage warning for diagnosis purposes. With respect to above mentioned points various analytical techniques have been developed for quantification of UA like fluorescence, chromatography, spectrophotometry and electrochemical methods [9-20].

In electrochemical methods, the electrode materials play a key role in improving the detection performances. Recently, many kinds of active materials, including carbon nanotubes, ionic liquids (ILs), metal oxides, graphene, and nanocomposites have been synthesized and then coated onto a solid substrate or dispersed into a conductive matrix to prepare the modified electrodes for the various electrochemical applications [21-42].

Graphene is a two dimensional (2-D) sheet of carbon atoms in a hexagonal configuration with atoms bonded by sp^2 bonds. These bonds and this electron configuration provide this material with extraordinary properties, such as large surface area, theoretically 2630 m^2/g for a single layer, and double that of single-walled carbon nanotubes (SWCNTs). It also shows excellent thermal and electrical conductivity. Due to its unique electronic properties, large surface area, rich edge defects, a tunable band gap, room-temperature Hall effect, strong mechanical strength, high elasticity and thermal conductivity; it exhibits remarkable electrocatalytic, conductivity, and sensing capability [43-53].

In the present work Fe_3O_4@SiO_2/GO nanocomposite was synthesized and exploited for modification of glassy carbon electrode and used for sensitive determination of MD and UA. It is worth mentioning that MD and UA oxidized in nearly same potential at bare glassy carbon electrode but modification of bare electrode with Fe_3O_4@SiO_2/GO nanocomposite brings about peak separation of overlapping peaks of MD and UA and makes it possible to simultaneously determine MD and UA. Performance of this newly fabricated nanosensor was studied using various electrochemical techniques. This sensor exhibited good sensitivity, selectivity and acceptable reproducibility for determination of MD and UA.

2. EXPERIMENTAL

2.1. Apparatus and chemicals

The electrochemical measurements were performed with an Autolab potentiostat/galvanostat (PGSTAT 302 N, Eco Chemie, the Netherlands). The experimental conditions were controlled with General Purpose Electrochemical System (GPES) software. An Ag/AgCl/KCl (3.0 M) electrode as reference electrode, a platinum wire as auxiliary electrode, and the $GO/Fe_3O_4/SiO_2$/GCE as working electrode were used.

Methyldopa, uric acid, and all other reagents were of analytical grade and were obtained from Merck chemical company (Darmstadt, Germany). The buffer solutions were prepared from orthophosphoric acid and its salts in the pH range of 2.0-9.0. $Fe_3O_4@SiO_2/GO$ nanocomposite was synthesized in our laboratory as reported previously [54].

2.2. Preparation of the electrode

GCE was prepared by mechanically polishing a glassy carbon electrode with 0.05 µm Al_2O_3 in water slurry then, it was electrochemically activated in a 0.1 M sodium bicarbonate solution, and pouring 5 µL of $GO/Fe_3O_4/SiO_2$ nanocomposite suspension (0.01 g/1 mL) onto the activated GCE surface.

3. RESULTS AND DISCUSSION

3.1. Electro-oxidation of MD at a $GO/Fe_3O_4/SiO_2$/GCE

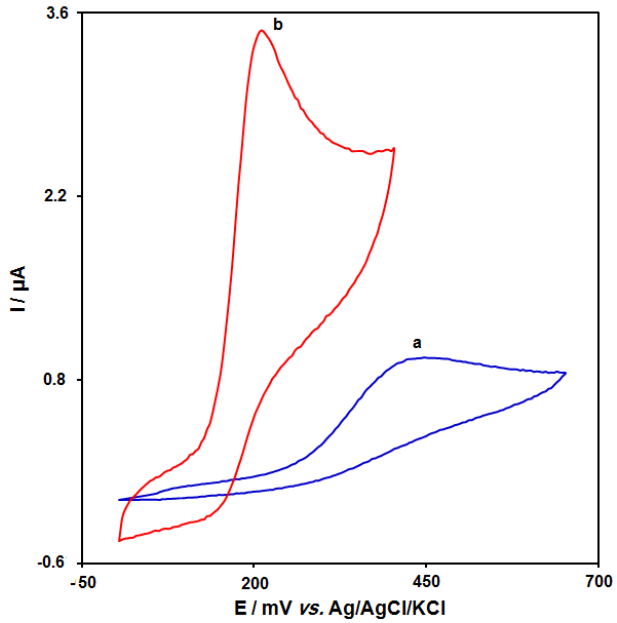

Figure 1. Cyclic voltammograms of (a) bare GCE and (b) $GO/Fe_3O_4/SiO_2$/GCE in PBS containing 0.1 mM MD at the scan rate 20 mVs^{-1}.

Fig. 1 depicts the cyclic voltammetric responses for the electrochemical oxidation of 0.1 mM MD at GO/Fe_3O_4/SiO_2/GCE (curve b) and bare GCE (curve a). The anodic peak potential for the oxidation of MD at GO/Fe_3O_4/SiO_2/GCE (curve b) is about 215 mV compared with 440 mV for that on the bare GCE (curve a). Similarly, when the oxidation of MD at the GO/Fe_3O_4/SiO_2/GCE (curve b) and bare GCE (curve a) are compared, an extensive enhancement of the anodic peak current at GO/Fe_3O_4/SiO_2/GCE relative to the value obtained at the bare GCE is observed. In other words, the results clearly indicate that Fe_3O_4@SiO_2/GO nanocomposite improve the MD oxidation signal.

The effect of sweep rates on the oxidation process has been studied (Fig. 2). The results showed that oxidation process is diffusion controlled as deduced from the linear dependence of the anodic peak current (I_p) on the square root of the sweep rate ($v^{1/2}$).

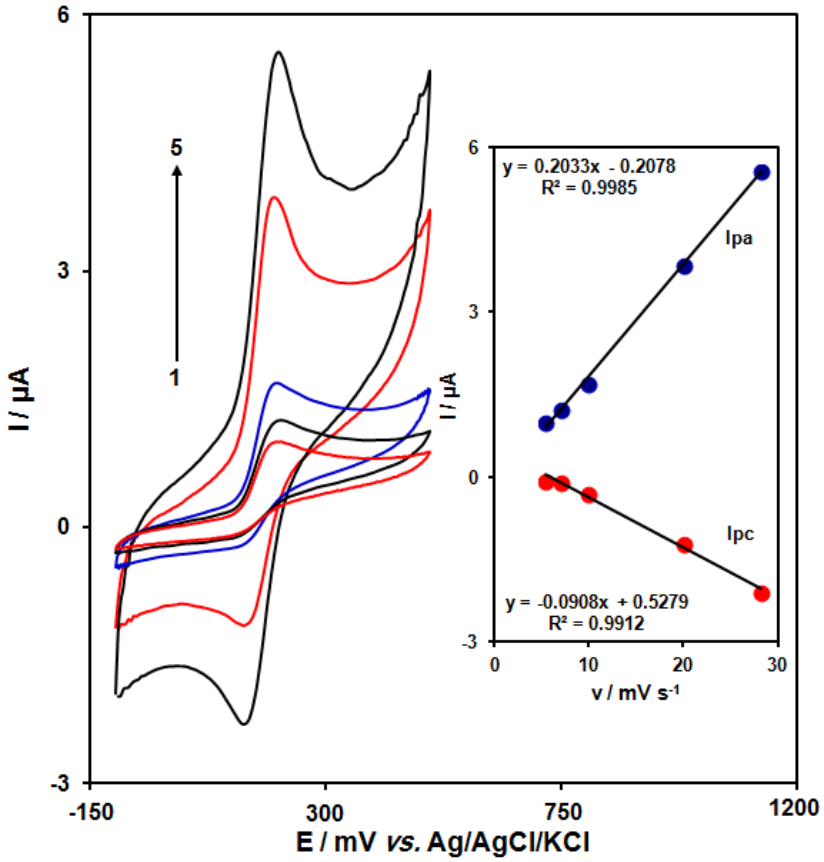

Figure 2. Cyclic voltammograms of GO/Fe_3O_4/SiO_2/GCE in PBS containing 30.0 µM MD at various scan rates; numbers 1-5 correspond to 30, 50, 100, 400 and 800 mV s^{-1}, respectively. Insets: Variation of anodic and cathodic peak current vs. square root of the sweep rate.

3.2. Chronoamperometric studies

Chronoamperometric measurements of MD at GO/Fe_3O_4/SiO_2/GCE were carried out by setting the working electrode potential at 0.3 V for the different concentration of MD (Fig. 3).

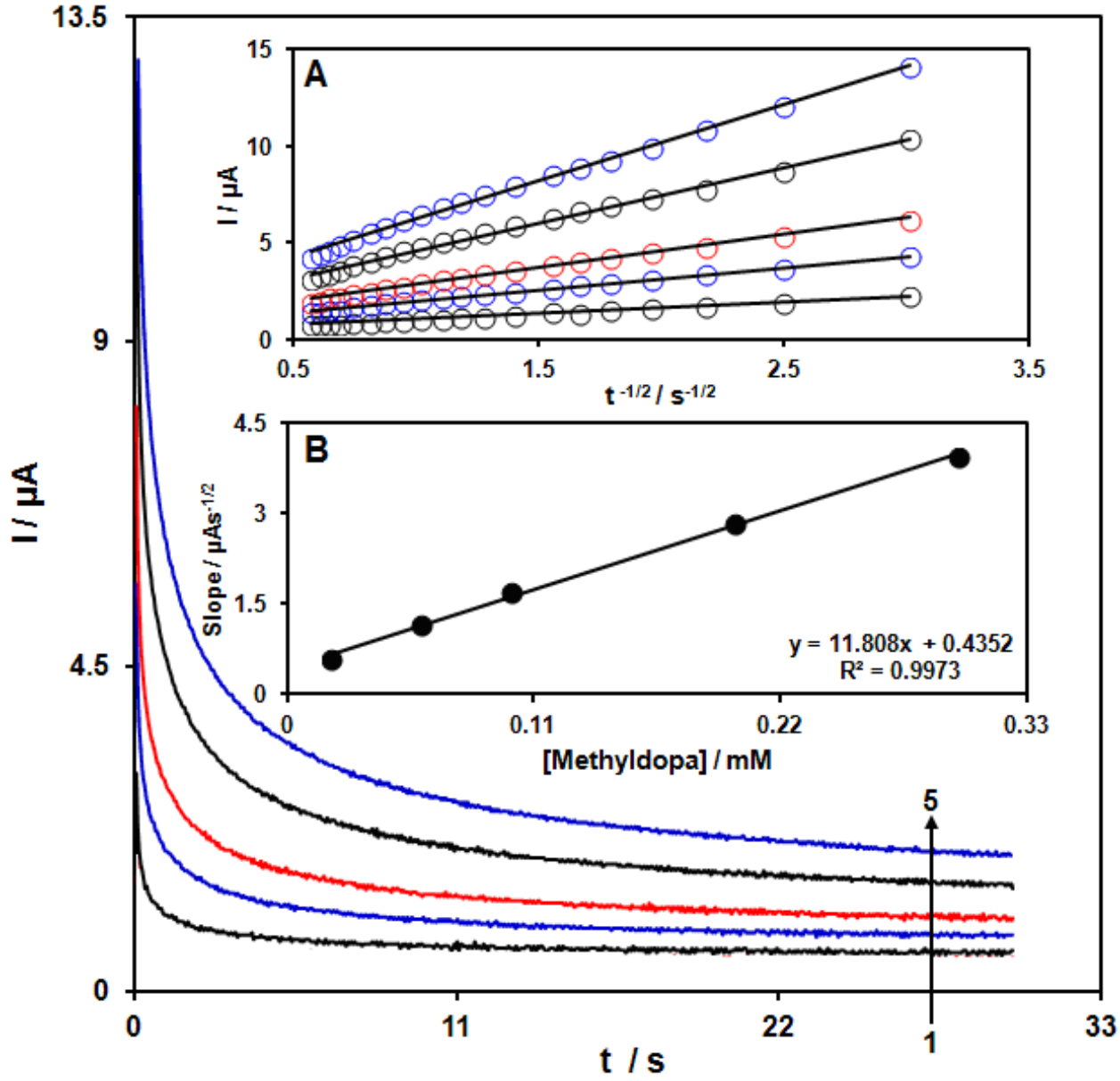

Figure 3. Chronoamperograms obtained at $GO/Fe_3O_4/SiO_2/GCE$ in PBS containing different concentrations of MD. The numbers 1–5 correspond to 0.02, 0.06, 0.1, 0.2 and 0.3 mM of MD. Insets: (A) Plots of I vs. $t^{-1/2}$ obtained from chronoamperograms 1–5. (B) Plot of the slope of the straight lines against MD concentration.

Using Cottrell equation [57] the mean value of the D was found to be 1.19×10^{-5} cm^2/s.

3.3. Calibration plot and limit of detection

Differential pulse voltammetry (DPV) experiments were done for different concentrations of MD (Fig. 4).

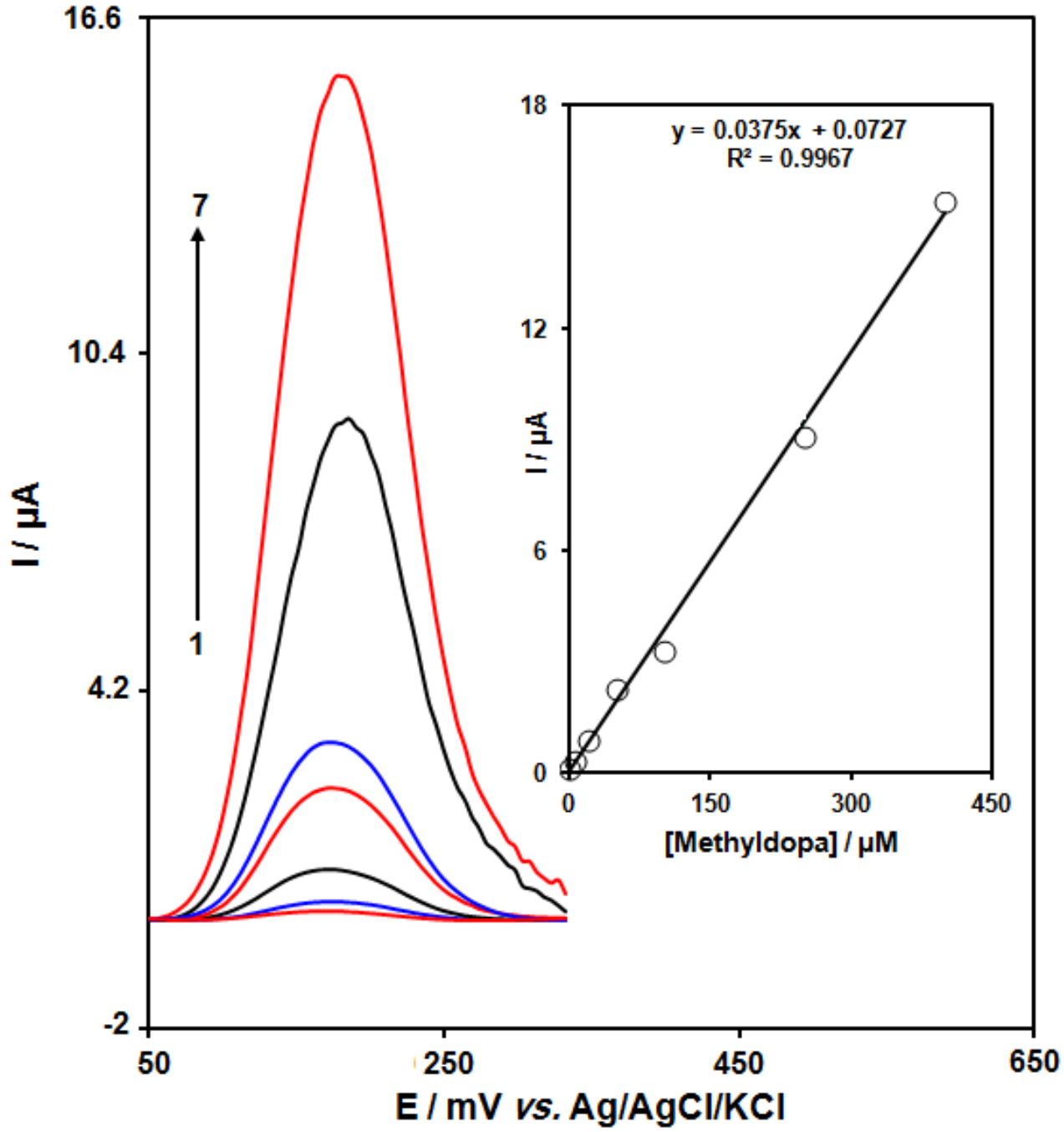

Figure 4. DPVs of GO/Fe_3O_4/SiO_2/GCE in PBS containing different concentrations of MD. Numbers 1–7 correspond to 0.1, 5.0, 20.0, 50.0, 100.0, 250.0 and 400.0 µM of MD. Inset: Plots of the electrocatalytic peak current as a function of MD concentration in the range of 0.1–400.0 µM.

The oxidation peak currents of MD at the surface of modified electrode were proportional to the concentration of the MD within the ranges 0.1 to 400.0 µM. The detection limit (3σ) of MD was found to be 8.6×10^{-8} M.

These values are comparable with values reported by other research groups for oxidation of MD at the surface of chemically modified electrodes (see Table 1).

Table 1. Comparison of the efficiency of some modified electrodes used in the electro-oxidation of methyldopa.

Electrode	Modifier	Method	LOD (M)	LDR (M)	Ref.
Glassy carbon	Pt–Ru nanoparticles/multi-walled carbon nanotubes	Voltammetry	10.0×10^{-9}	0.05×10^{-6}-4.0×10^{-5}	[58]
Glassy carbon	Carboxylated multiwall carbon nanotubes	Voltammetry	0.08×10^{-7}	0.1×10^{-6}-3.0×10^{-4}	[59]
Carbon paste	$Cu(OH)_2$ nanoparticles	Voltammetry	0.61×10^{-6}	2.0×10^{-6} – 4.5×10^{-4}	[60]
Glassy carbon	Multiwall carbon nanotubes	Voltammetry	10.0×10^{-9}	0.005×10^{-6} –38.8×10^{-4}	[61]
Fluorine-doped tin oxide electrodes	SnO_2 nanoparticles	Voltammetry	2.9×10^{-6}	2.0×10^{-6}– 6.0×10^{-5}	[62]
Carbon paste	NiO nanoparticles and an ionic liquid	Voltammetry	0.6×10^{-7}	1.0×10^{-7}– 7.0×10^{-4}	[63]
Glassy carbon	CdSe@Ag_2Se core–shell	Voltammetry	4.0×10^{-8}	9.0×10^{-8}– 6.0×10^{-5}	[64]
Glassy Carbon Electrode	Fe_3O_4@SiO_2/GO nanocomposite	Voltammetry	8.6×10^{-8}	1.0×10^{-7}-4.0×10^{-4}	This Work

3.4. Simultaneous determination of MD and UA

Determination of two compounds was performed by simultaneously changing the concentrations of MD and UA, and recording the DPVs (Fig. 5). The voltammetric results showed well-defined anodic peaks at potentials of 180 and 300 mV, corresponding to the oxidation of MD and UA, respectively.

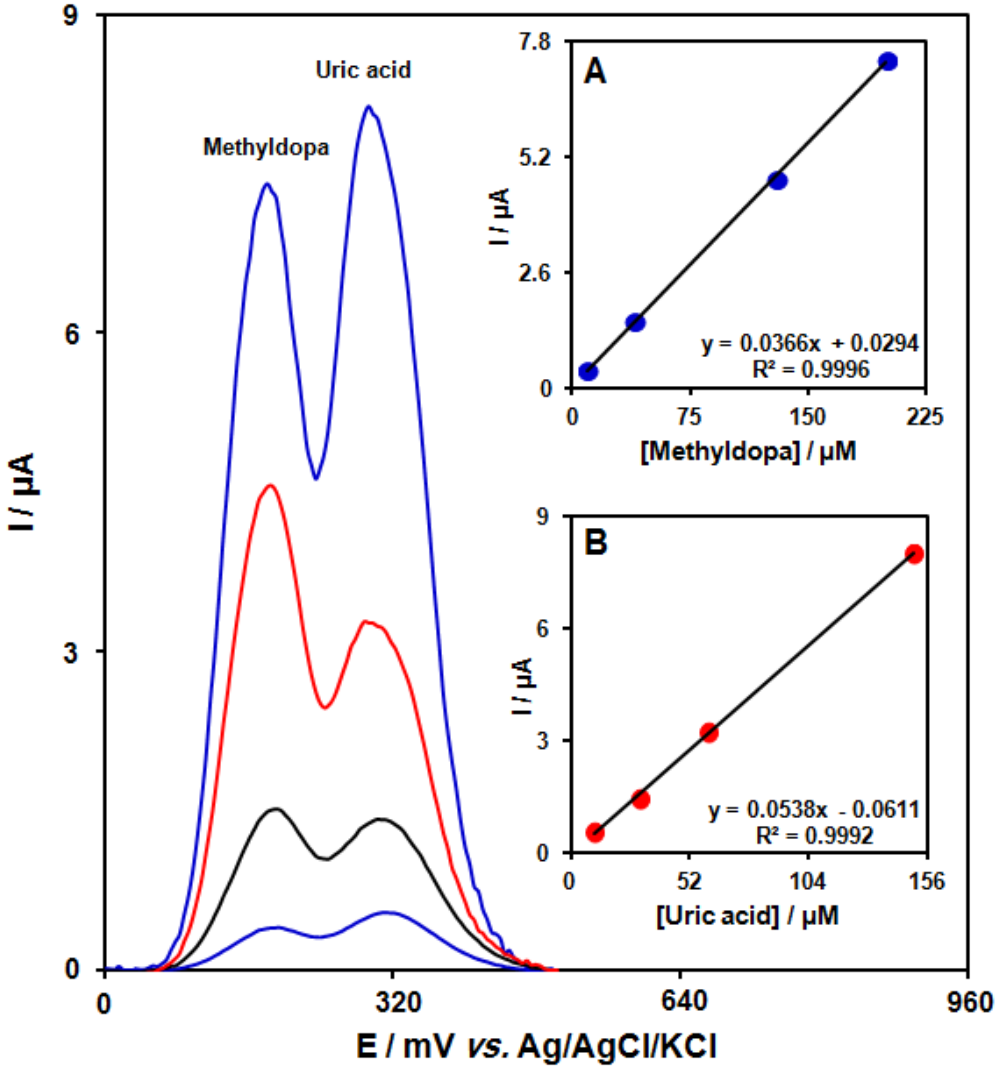

Figure 5. DPVs of GO/Fe_3O_4/SiO_2/GCE in PBS containing different concentrations of MD+UA in µM, from inner to outer: 10.0+10.0, 40.0+30.0, 130.0+60.0 and 200.0+150 respectively. Insets: (A) plot of Ip vs. MD concentrations and (B) plot of Ip vs. UA concentrations.

3.5. Real sample analysis

The proposed method was applied to the determination of MD and UA in MD tablet and urine samples. The results for determination of the two species in real samples are given in Table 2.

Table 2. The application of GO/Fe_3O_4/SiO_2/GCE for simultaneous determination of MD and UA in real samples (n=5). All concentrations are in µM.

Sample	Original content (µM)		Added (µM)		Found		Recovery (%)		R.S.D. (%)	
	MD	UA	MD	UA	MD	UA	MD	UA	MD	UA
MD tablet	10.0	0	0	0	9.9	-	99.0	-	2.8	-
	10.0	0	5.0	20.0	15.4	19.5	102.7	97.5	3.4	2.9

	10.0	0	10.0	30.0	19.8	31.1	99.0	103.7	1.7	3.3
Urine	0	15.0	0	0	-	15.1	-	100.7	-	3.2
	0	15.0	5.0	15.0	5.1	29.2	102.0	97.3	2.9	1.8
	0	15.0	10.0	20.0	9.7	35.6	97.0	101.7	2.8	2.4

4. CONCLUSIONS

The results show that the GO/Fe_3O_4/SiO_2/GCE can cause excellent electrocatalytic oxidation of MD. The GO/Fe_3O_4/SiO_2/GCE had desirable electrochemical features such as high sensitivity, selectivity, low detection limit, high stability and reproducibility. Other advantages of the proposed method are technical simplicity, and rapid preparation of the sensor. The constructed sensor was used for determination of MD and UA in some real samples.

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